SUNSHINE IN THE UNITED STATES.

By JOSEPH BURTON KINCER, Meteorologist.

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SYNOPSIS.—Sunshine is a very important climatic element, not only from the standpoint of the agriculturist, but also from its physical effect on man and other animals. The depressing influence on human beings of long periods of cloudy and damp weather is noticeable, even to the casual observer, while, on the other hand, long periods of successive days with continuous sunshine and high temperature are trying on all animal and plant life. Long hot periods are usually characterized by few clouds and much sunshine, when, day after day, the amount of insolation received during the daytime results in an accumulation of heat in excess of that lost at night by radiation. Finally a change in pressure conditions results in the breaking up of the stagnant atmosphere, bringing refreshing winds and welcome clouds to relieve the situation.

Sunshine data are recorded and expressed either in values giving the actual amount in hours and tenths, or by indicating the percentage of the possible amount. Each of these methods has advantages not possessed by the other. Owing to the large seasonal variations in the possible amount, the actual duration of sunshine from month to month is not disclosed directly by a statement of the percentage of the possible. For in such case, a knowledge of the latter is necessary before the actual amount can be determined. For example, along the north-central border of the United States, a day with four hours of sunshine the latter part of December would have 50 per cent of the possible, while a like amount the latter part of June would be only 25 per cent of the possible. On the other hand, the percentage of the possible amount gives a better direct indication of the seasonal variations in cloudiness than do data showing the actual number of sunshine hours. Published sunshine data for the United States are given mostly in values showing the percentage of the possible amount.

In view of the advantages possessed by each of these methods of presenting data, they are given in this study in both values and in considerable detail. Charts and graphs are presented showing the mean solar time of sunrise and sunset, and the average length of the day, sunrise to sunset, representing the possible maximum amount of sunshine for different seasons of the year. Included is a series of charts showing for each month the average amount of sunshine in hours per day; also charts and graphs showing the seasonal and annual distribution in percentages of the possible amount. Other charts show the percentage of days clear, partly cloudy, and cloudy, while the diurnal distribution of sunshine is also graphically shown. There is included a table showing for each month and for the year the average percentage of the possible amount of sunshine for all stations where continuous automatic records are made, which include practically all regular reporting stations. The basic data are for the 20-year period from 1895 to 1914, except that the percentages of the possible amount are for the 8-year period from 1905 to 1912.

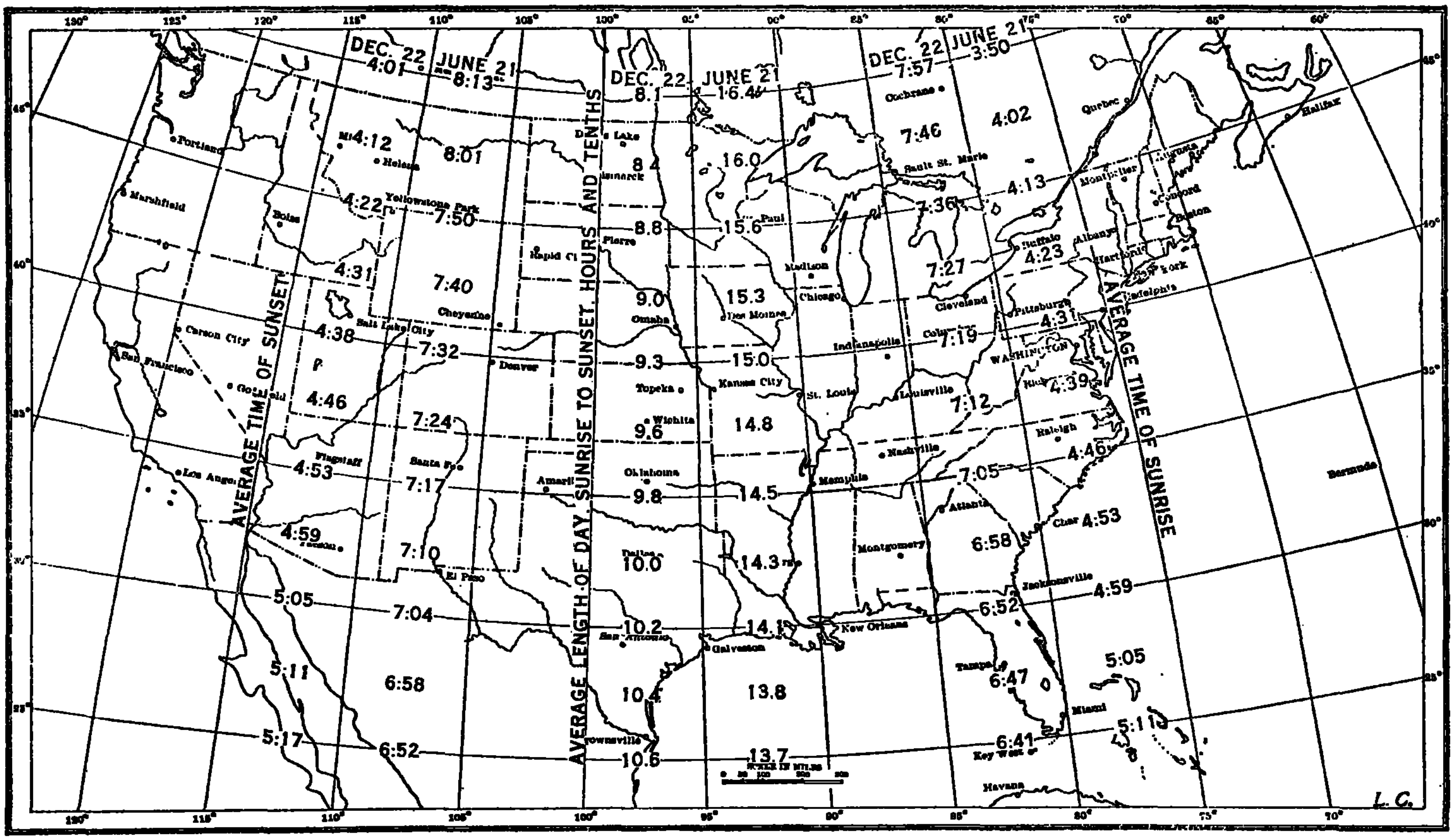


FIG. 1.—The average mean solar time of sunrise and sunset and the average length of the day, sunrise to sunset, on December 22 and June 21, for each two and one-half degrees of latitude.

VARIATIONS IN THE POSSIBLE AMOUNT OF SUNSHINE.

With an ideal sea-level horizon, the amount of sunshine received in any locality for the year as a whole would be determined by the prevailing state of the sky as to presence or absence of clouds and fog, although there is a slight increase with latitude in the possible amount of yearly sunshine. This variation is unimportant, however, amounting in the course of the year to a total of only about 35½ hours between latitudes 25° and 49° north, representing the extreme southern and extreme northern portions of the United States; the average possible yearly amount at latitude 25° is 4,437.2 hours and at latitude 49°, 4,472.6, for a 365-day year.

The possible amount of sunshine, however, has wide seasonal variation in middle and high latitudes, the variations increasing rapidly with the latitude. It varies from week to week throughout the year, being greater in higher than in lower latitudes in summer, and vice versa in winter. The time of sunrise and sunset at a given place when expressed in mean solar time varies from day to day, depending upon the declination of the sun, while variations in the equation of time, the apparent diameter of the sun, and the atmospheric refraction at the points of sunrise and sunset also affect the results. Moreover, these quantities, as well as the solar declination, do not have the same values on corresponding days from year to year. It follows, then, that in a general table showing the time of sunrise and sunset, the exact time is represented only approximately, but even in extreme cases the error is not material, being only two or three minutes per day.

For comparison as to the possible amount of sunshine that could occur in different portions of the United States, and to indicate the seasonal variations in amount, figures 1 and 2 are presented. Figure 1 shows for each two and one-half degrees of latitude the average mean solar time of sunrise and sunset and the average length of the day, from sunrise to sunset, on December 22 and June 21, or the time of the winter and summer solstice, which represent the shortest and the longest days, respectively, of the year. At the time of the equinoxes, about March 21 and September 22, the days and nights are substantially of equal length, not only in all portions of the United States but throughout the world.

It will be noted from figure 1 that during the season of longest days of the year the sun rises at the northern end of a north-and-south line drawn through the center of the United States from the northern to the southern boundary about one hour earlier than at the southern end, and that this condition is reversed during the period of the shortest days of the year. Figure 2 shows the variations from month to month in the length of the day, from sunrise to sunset, at latitudes 25°, 37°, and 49°. The vertical bars to the right of this graph visualize the amplitudes of variations for the latitudes given. It will be noted that while the longest day of the year at latitude 25°, extreme southern Florida, is only about three hours longer than the shortest day, at latitude 49°, representing the northwestern boundary of the country, the longest day is eight hours longer than the shortest. The actual amount of sunshine received in different portions of the United States varies greatly, however, from these potential amounts.

REGISTRATION OF SUNSHINE.

The sunshine data collected by the Weather Bureau are not entirely satisfactory, owing to the fact that the automatic recording instruments available to the present time do not indicate the different degrees of sunshine intensity, and it is very desirable that a more satisfactory instrument be devised. There are three forms of sunshine recorders in use: These are the Campbell-Stokes burning recorder, consisting of a lens or burning glass which scorches, during bright sunshine, a trace on a strip of cardboard placed at the proper focal distance and adjusted by clockwork to revolve with the sun; the Jordan, or photographic recorder; and the electical thermometric recorder, now in general use by the Weather Bureau. The last-named instrument consists essentially of a straight glass tube with a cylindrical bulb at each end, the lower bulb, as exposed for service, being coated on on the outside with lampblack, and the whole inclosed in a protecting glass sheath, the space between the inner tube and the protecting sheath being exhausted of air and hermetically sealed. Mercury is used to separate the air in the bulbs, and two wires are inserted through the inner tube about midway between the bulbs, but above the point the top of the mercury column assumes in the absence of sunshine. The ends of the wires within the inner tube are slightly separated, but are so arranged that the electric circuit will be closed by the mercury coming in contact with them. The instrument operates by the greater expansion of the air in the lower, blackened bulb and also of the mercury in the tube, caused by the heat of the sun's rays, this expansion causing the top of the mercury column to move upward and make contact with the ends of the wires. With the cessation of sunshine, contraction causes the reverse operation and the circuit is opened. The instrument is therefore a kind of thermometer, and, owing to its somewhat sluggish action, when the sky is partly covered with floating clouds the presence or absence of sunshine for short periods may not be recorded. In general, however, the time lost should about equal that gained and the record is not thereby materially vitiated. The instrument is

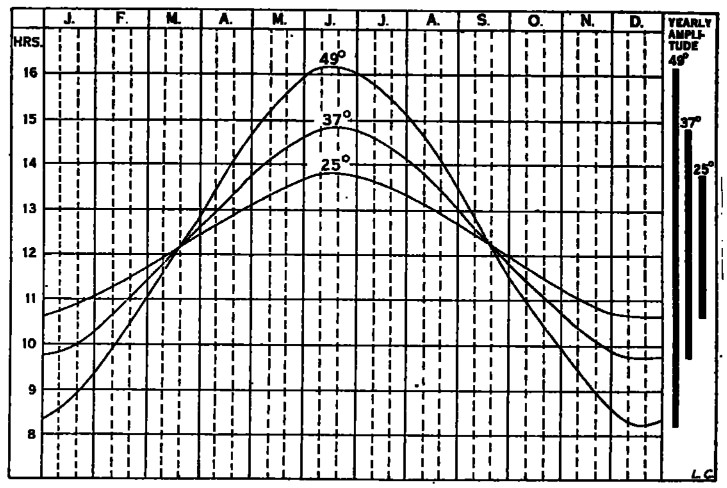


FIG. 2.—Seasonal variations in the length of the day, sunrise to sunset, at latitudes 25°, 37°, and 49°.

not delicate enough to record sunshine in the early morning immediately after the sun appears above the horizon, and likewise the sun's rays usually become too weak to maintain a record somewhat before sunset. In such cases the actual unrecorded sunshine is noted by personal observations, and the records are corrected by adding thereto, when the sun is shining, the interval between actual sunrise and the beginning of the automatic record, and that between the ending of the record and the time of actual sunset.

SUNSHINE DATA.

Sunshine data may be expressed as the number of hours of daily sunshine, or as percentage of the possible amount. When given in the latter values, the actual amount can be determined only with a knowledge of the possible amount, or that which would be received with continuously clear sky. There are included with this paper charts and tables showing the annual, seasonal, and diurnal variations of sunshine in the United States by both classes of values. The installation of automatic sunshine recorders was begun at Weather Bureau stations in the early nineties, and a few years thereafter practically all of the regular reporting stations were equipped with these instruments.[1]

There appeared in the November, 1919, MONTHLY WEATHER REVIEW **47 : 769–793**; an extensive paper, by

[1] See "Bibliographic note on sunshine in the United States," by R. DeC. Ward, MONTHLY WEATHER REVIEW, Nov., 1919, 47; 794–795.

Prof. Kimball on the variations of the total and luminous solar radiation with geographic position in the United States, in which these variations (expressed in gram-calorie units), with latitude, altitude, slope, and varying atmospheric conditions, were discussed in detail, with numerous illustrations and tables of observational and computed values. The paper here presented has a more or less direct relation to that of Prof. Kimball in so far as the actual amount of sunshine received in different sections of the country and the seasonal variations are concerned. Attention is especially invited to figure 3 in that paper, showing the variations in solar radiation intensity with latitude, and also to figures 10 and 11, showing the average seasonal potential totals of radiation on a horizontal surface and the actual average amounts, based on the degree of cloudiness prevailing in different sections of the country.

GEOGRAPHIC DISTRIBUTION OF SUNSHINE.

Figure 3 shows the geographic distribution of sunshine for the year as a whole, expressed in percentage of the possible amount, the latter being essentially the same for all sections of the country, or an average of approximately 12 hours a day. This chart shows that the least amount is received along the north Pacific coast, where the sun shines on the average for the year during only about 40 per cent of the daylight hours, while in the Lake region, the central and northern portions of the Appalachian Mountain area, and the Northeast, the percentages are only slightly higher, 45 to 50. In the remaining districts east of the Mississippi River and in the northern States from the upper Great Lakes westward to the Rockies, the percentages range from 50 to 60, except that they are somewhat higher in the Southeast, especially in the Florida Peninsula. Between the Mississippi River and the Rocky Mountains the annual percentage is generally between 60 and 70, which is also true for the central Rocky Mountain region and northern Plateau States. The maximum amount of sunshine in the United States is received in the far Southwest, including extreme western Texas, New Mexico, Arizona, southern Nevada, and the adjoining portions of California. In the lower Colorado River Valley the sun shines on the average for the year nearly 90 per cent of the total number of hours from sunrise to sunset.

Figure 3 shows also the percentage of the possible amount of sunshine for each of the four seasons—winter, spring, summer, and fall. In winter the percentages range from less than 30 in the far Northwest and in portions of the Lake region, to more than 80 in the far Southwest; in spring, the variations for the same regions are from 40 to 50 in the former, to about 90 in the latter. In summer the extremes in percentages are 40 along the northern California coast to 95 in the Great Valley of California, while in fall they range from about 35 in limited areas in the Lake region to more than 90 in the lower Colorado River Valley. For the country as a whole the average annual percentage of the possible amount of sunshine is nearly 60 per cent, distributed through the seasons as follows: Winter, 48 per cent; spring, 60 per cent; summer, 68 per cent; fall, 60 per cent.

In some sections of the country the seasonal variations in the amount of sunshine, when expressed in percentage of the possible amount, are pronounced, while in others the distribution is quite uniform throughout the year. The interior districts, as a rule, have the more uniform values, while the Pacific Coast States and the region of the Great Lakes have wide variations.

Figure 7 presents data showing the seasonal variations for three selected stations where the distribution of sunshine is uniform throughout the year; these are for Yuma, Ariz., Denver, Colo., and Washington, D. C. This graph shows, also, similar data for three other stations where the seasonal variations are large—Fresno, Calif., Tacoma, Wash., and Binghamton, N. Y. The record for Yuma shows uniformly high percentages, and those for Denver and Washington uniform and moderately high values while the others show widely varying seasonal amounts.

Table 1 gives the average percentage of the possible amount of sunshine, by months and also for the year, for all regular reporting stations of the Weather Bureau equipped with automatic sunshine recorders. In the

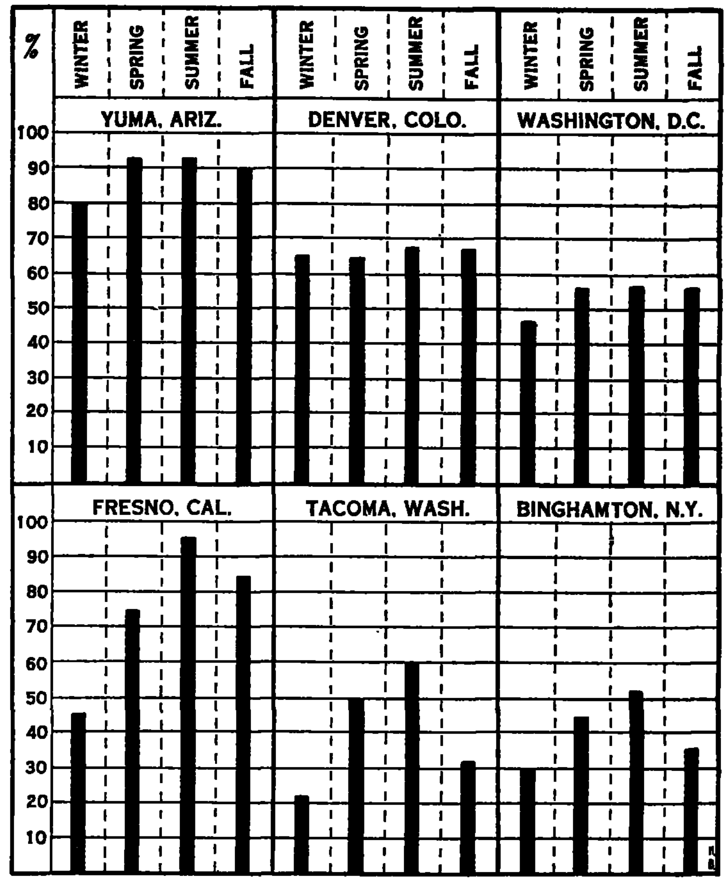


FIG. 7.—Seasonal variations in amount of sunshine.—Selected stations, showing uniform distribution in some localities and wide variations in others.

southeastern portions of the United States the spring months are the sunniest, while in much of the Ohio Valley and the Southwest June has a higher percentage of sunshine than any other month. July is the month of maximum in nearly half of the country, including all northern districts. The smallest percentage of the possible amount in much of the interior, and in the central and southern Pacific Coast districts and Southern Plateau States occurs in January, which is also the case in the Middle Atlantic States; in most other districts December is the cloudiest month.

SEASONAL VARIATIONS OF SUNSHINE.

Figures 4 and 5 show for the different sections of the United States, for each month of the year, the average number of hours of daily sunshine. These charts indicate the seasonal distribution of this important climatic

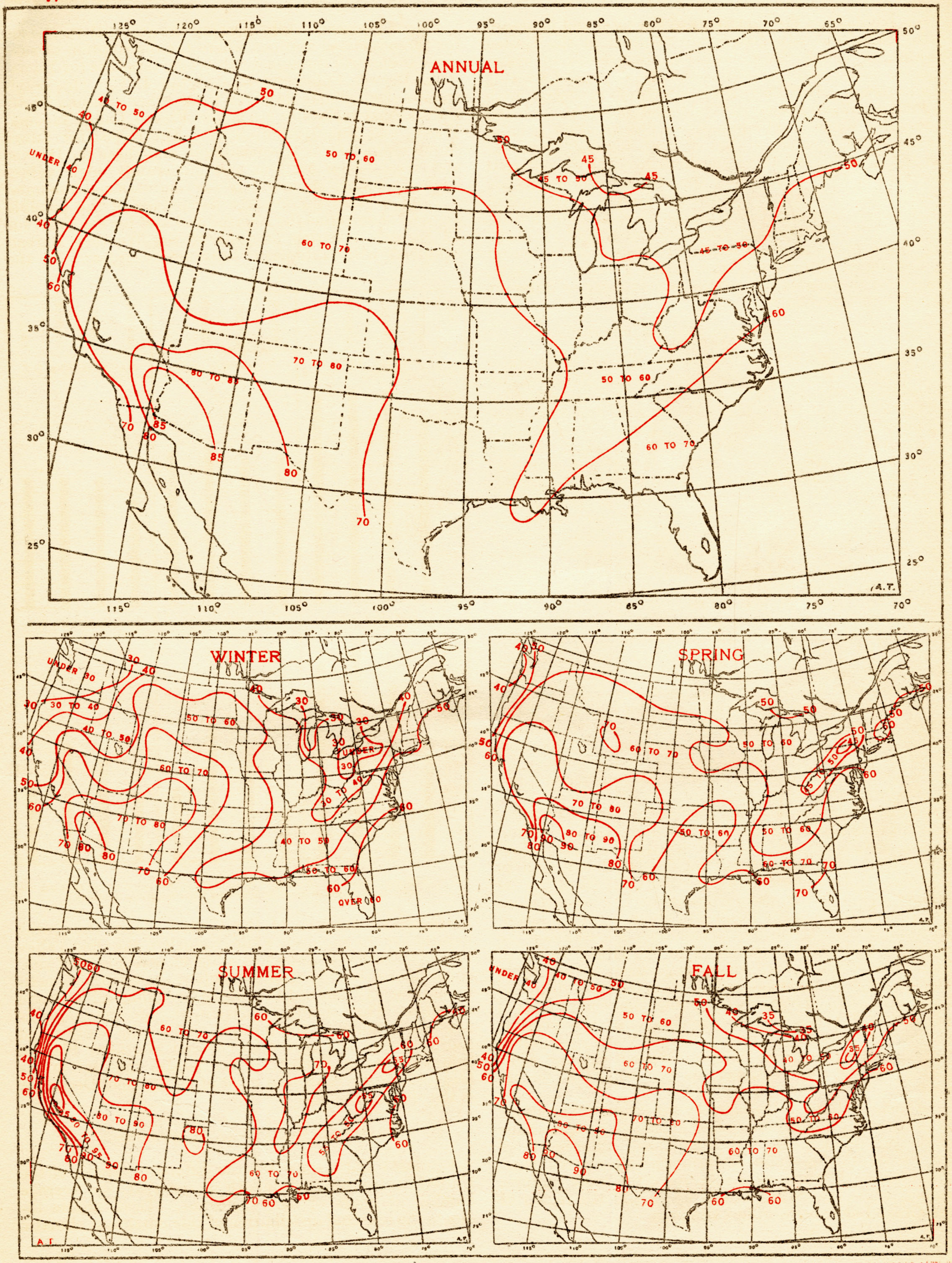


FIG. 3.—Percentage of possible amount of sunshine.

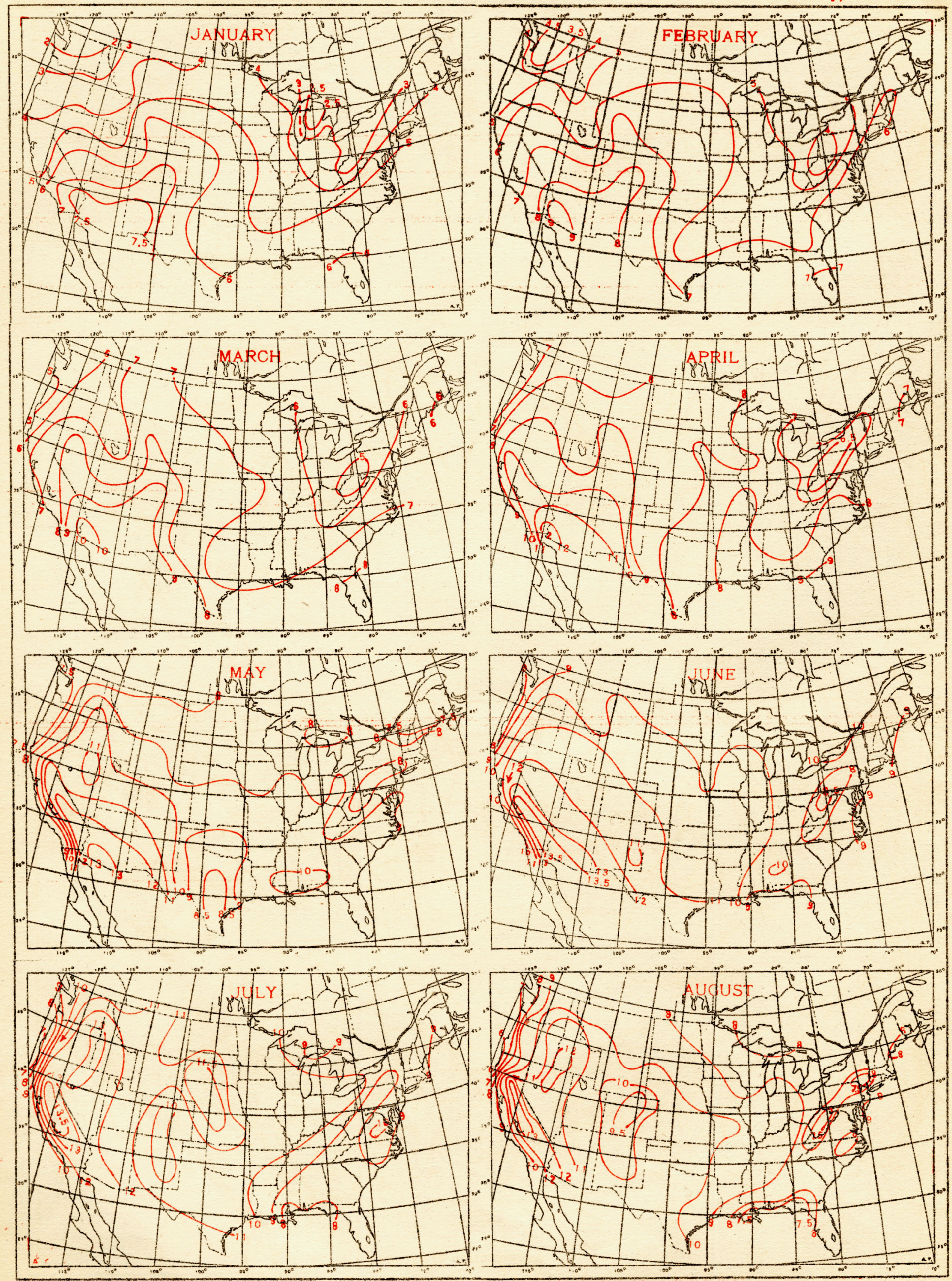
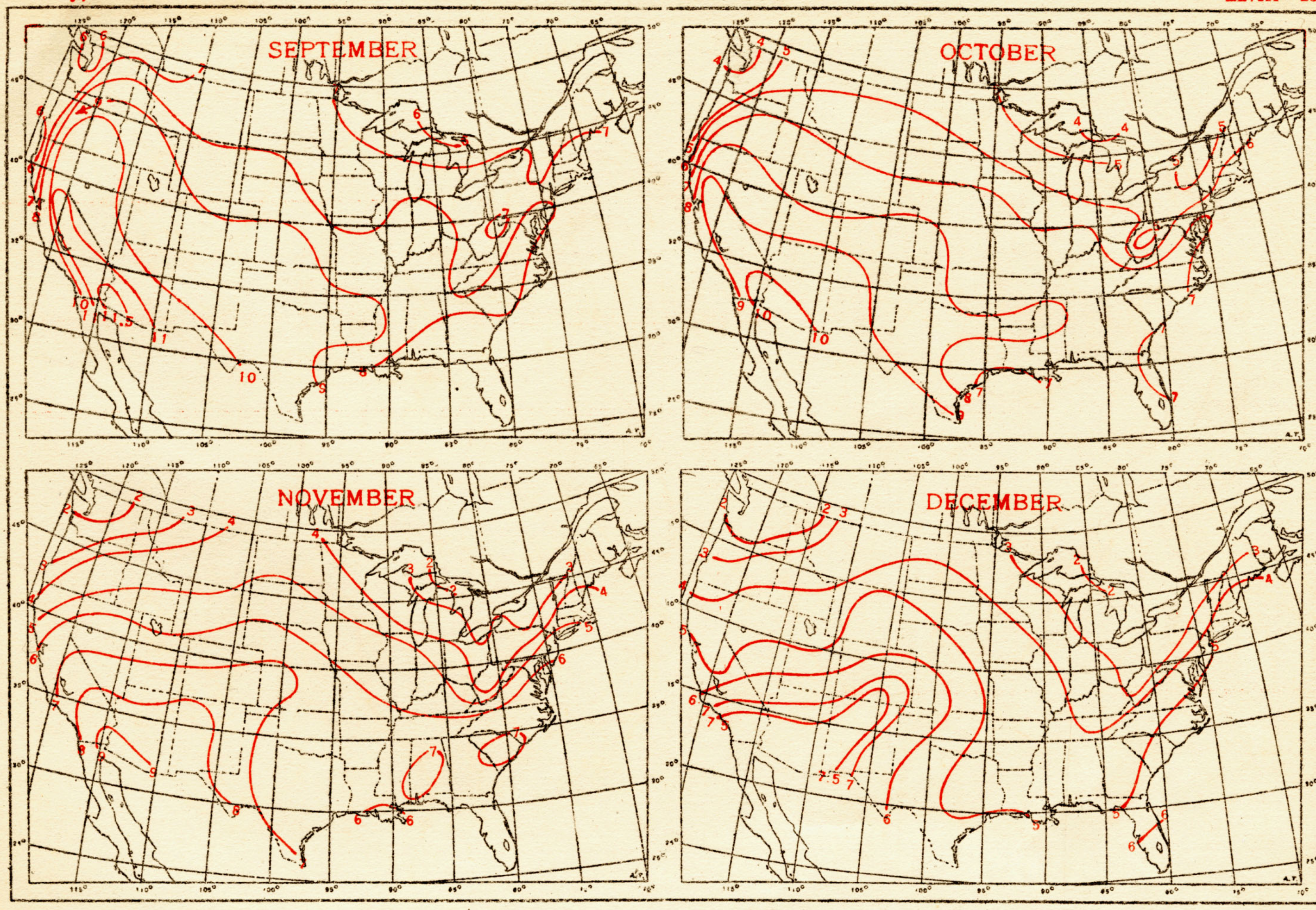


FIG. 4.—Average amount of sunshine daily, hours.



Average amount of sunshine daily, hours.

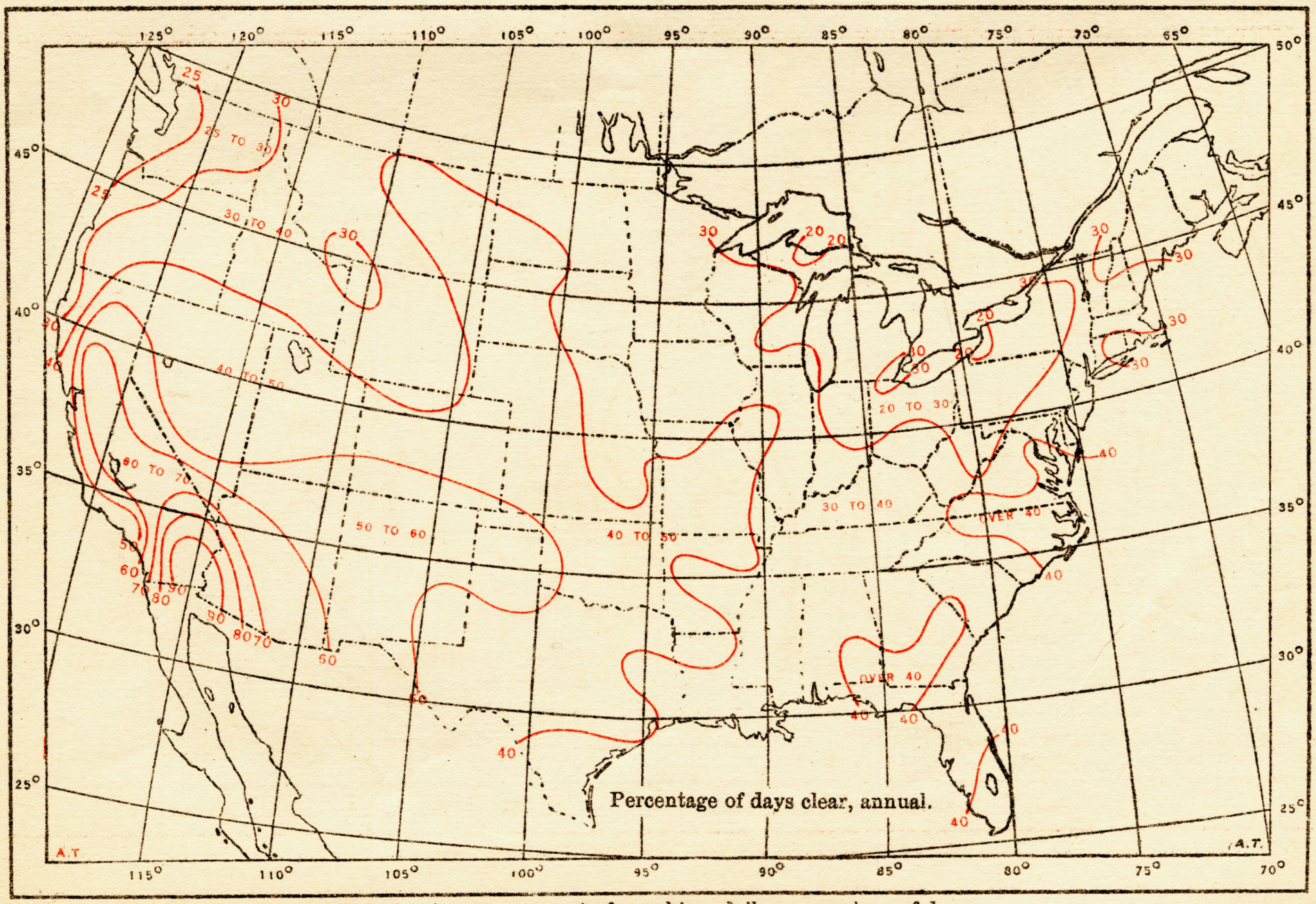
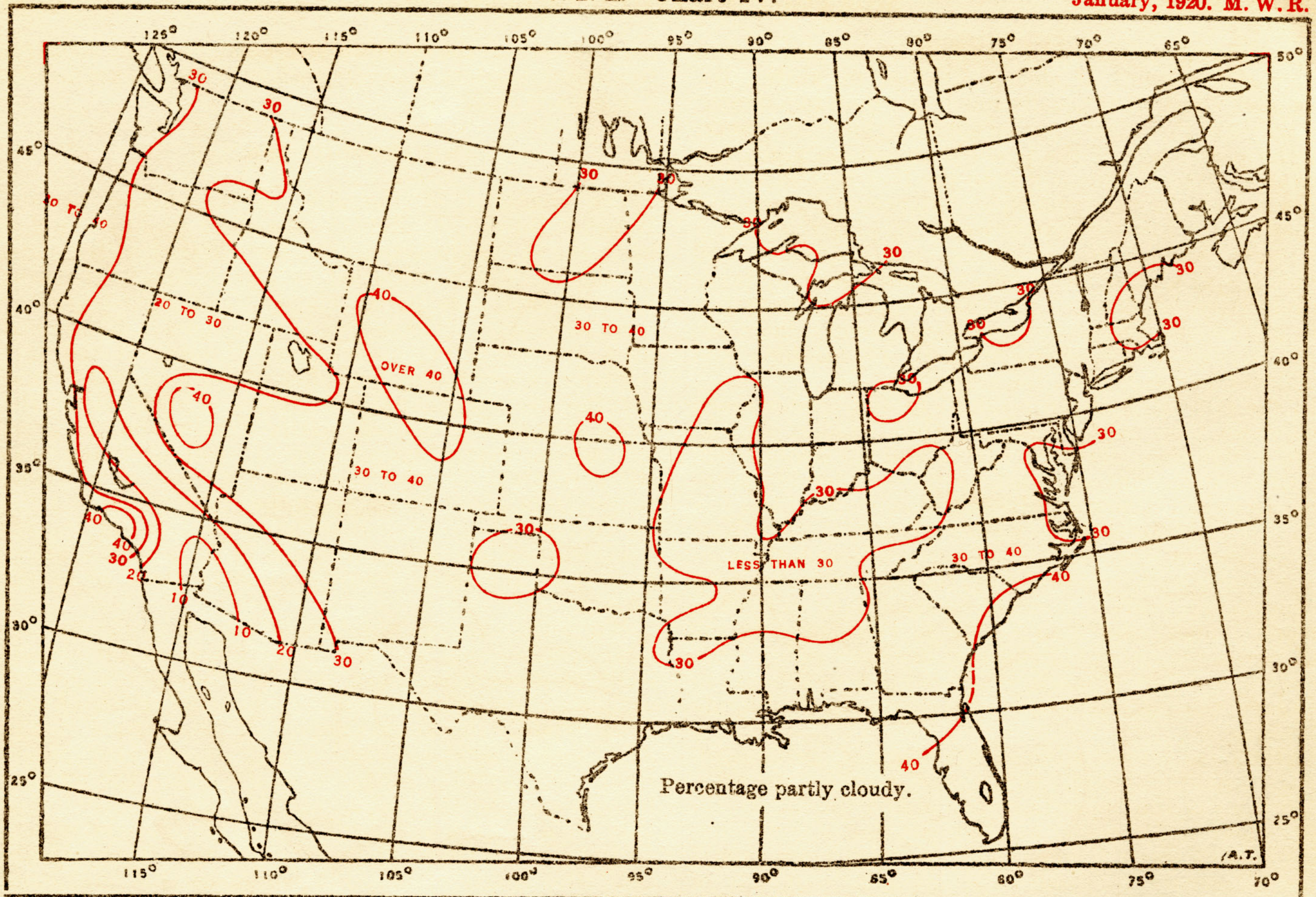


FIG. 5.—Average amount of sunshine, daily; percentage of days clear, annual.



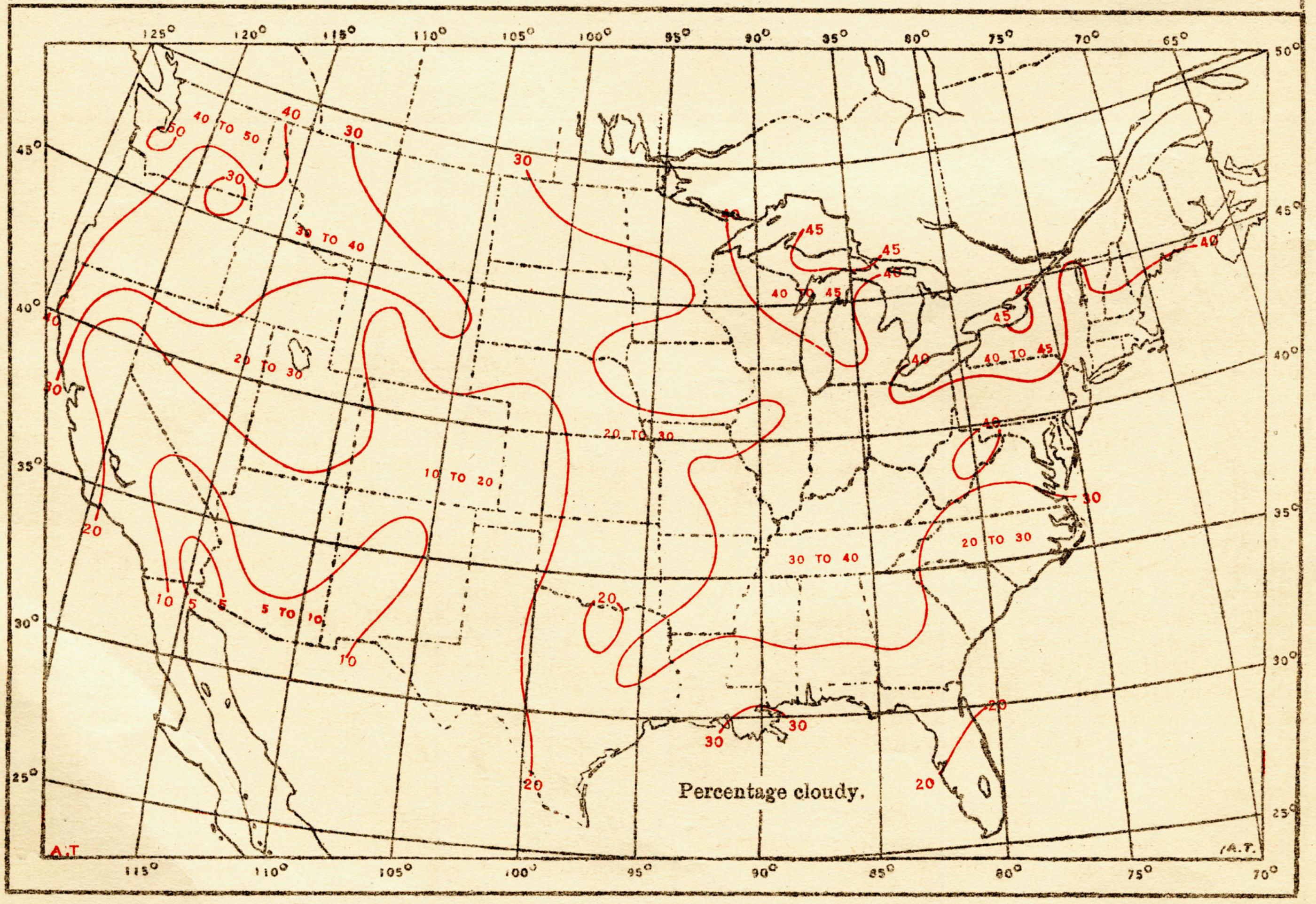


Fig. 6.—Percentage of days partly cloudy, and of days cloudy, annual.

factor. Owing to the fewer daylight hours, and also to the greater amount of cloudy weather in winter, the amount of sunshine is usually much less than in summer. Not only are there fewer actual sunshine hours in winter but the percentage of the possible amount is much less than in summer. This is due to the fact that in winter cyclonic action is more pronounced and several successive days of cloudy weather may be experienced in the passing of a storm, while in summer, cloudy weather and rainfall are usually of a more local character and there are fewer entirely overcast days. Cumulus clouds are characteristic of the summer season and consequently there are frequently successive short intervals of sunshine and cloudiness, particularly in the afternoon.

In the late fall and during most of the winter much cloudy weather prevails in the Great Lakes and in western Montana, northern Idaho, and in Washington, the average amount of sunshine in considerable areas being less than 3 hours daily and in some localities less than 2 hours. In extreme western Texas, most of New Mexico, and Arizona, and in southern California the winters, on the other hand, are sunny, these districts receiving on the average nearly 8 hours of sunshine daily in December and January, and 8 to 9 hours in February. In the Gulf States the amount of sunshine in winter ranges from an average of 4 to 5 hours in December to 6 or 7 hours in February, the maximum amount occurring in the Florida Peninsula.

With the advent of spring the amount of sunshine increases rapidly, especially in the more northern districts. In portions of the upper Lake region and the far Northwest, where in December and January the average sunshine is only about 2 hours daily, in April more than 7 hours is usually received. The maximum amount of sunshine during this season is received in the lower Colorado River Valley, where the average for the three spring months is about 12 hours a day, or 90 per cent of the possible amount. By May, there is an average of 9 to 10 hours of sunshine daily in the interior districts of the country.

The increase in the amount of sunshine from winter to summer in the northern portion of the United States is very pronounced. In most of the northern border States there are on the average in July about 6½ hours of daily sunshine in excess of that received in January. In the South the increases are not so pronounced, the daily July excess over January in the central and eastern Gulf States being only about 3 hours. East of the Rocky Mountains the geographic distribution of sunshine in summer is in general the reverse of that in winter, the northern districts receiving more than the southern. Much of the central and northern Great Plains usually receives in July from 40 to 50 per cent more sunshine than occurs along the central and east Gulf coast. The maximum summer amount for the country as a whole is experienced in the Great Valley of California and over the western portion of the Plateau region. The interior of California has almost continuous cloudless skies during the summer months, the average daily amount of sunshine in most of the Great Valley being nearly 14 hours, or about 95 per cent of that possible.

In autumn, especially during October and November, much cloudy weather is experienced in the region of the Great Lakes, the upper Ohio Valley, and the far Northwest, where in some places the average daily amount in November is less than 2 hours, but at the same time the daily averages in portions of the Southwest are in excess of 9 hours. In the fall, there is a uniform and rather marked increase in the amount of sunshine from the northeastern to the southwestern portions of the country. In interior districts the averages for this season are mostly 7 or 8 hours daily.

CHARACTER OF THE DAY.

The character of the day, as determined by the Weather Bureau, is divided into three groups. A day when the sky is three-tenths or less covered with clouds, on the average, is recorded as clear; from four-tenths to seven-tenths as partly cloudy; and eight-tenths or more as cloudy. The degree of cloudiness is determined by a number of eye observations throughout the day.

Figures 5 and 6 show for different sections of the country the average annual percentage of days clear, the average annual percentage partly cloudy, and the average annual percentage cloudy. It will be noted that the percentage of days clear for the year, as a whole, ranges from about 20 to 25 in the Lake region and the far Northwest to more than 85 in portions of the far Southwest; while the percentage of days cloudy range from 5 in the latter locality to more than 40 in the former.

While the extreme duration of periods of cloudy and clear weather that has been experienced is not climatically of great importance, it is of interest in a general discussion of sunshine and cloudiness. East of the Great Plains, the longest period of consecutive cloudy days that was experienced during the 20-year period from 1895 to 1914, ranged from 12 to 16, the number being about the same in all sections, except that it was only about 8 days in Florida, but 20 in the Lake region. In the western Great Plains, the southern Rocky Mountain, and much of the Plateau areas, the maximum number of successive cloudy days was about 10 in most localities, and ranged in the Pacific Coast States from 8 in southern California to 20 in western Washington. From the Mississippi Valley eastward the longest period of consecutive clear days experienced during these 20 years was generally about 15 days, except that in the Lake region it was about 10 and in Florida 20 days. In the Great Plains the longest clear period varied from 12 days in the central portion to 20 or more in both the northwestern and southern portions. In the western Plateau States and in the interior of California from 50 to 80 consecutive clear days were recorded during this period, but 10 was the limit along the north Pacific coast.

DIURNAL VARIATIONS IN SUNSHINE.

In general, the amount of sunshine is less during the early morning hours, with a secondary minimum in the late afternoon. The greatest amount occurs near midday.

Figure 8 shows the diurnal distribution of sunshine for several sections of the country, based on the average of five or six stations for each area designated, the areas covered being the Atlantic Coast States, the Gulf region, the interior, and the immediate Pacific coast districts. It will be noted from this graph that for the year, as a whole, the diurnal distribution of sunshine is quite uniform in all sections of the country. There are, however, wide seasonal variations in some localities, as is indicated by figure 9, which shows for the summer season—June to August, inclusive—the diurnal distribution of sunshine at San Diego and Fresno, Calif., Kansas City, Mo., and Tampa, Fla. At Fresno and Kansas City during the summer season sunshine is distributed rather uniformly throughout the day, but at San Diego the afternoons are much sunnier than the mornings, while at Tampa these conditions are reversed. For the winter season in these localities the large variations do not appear.

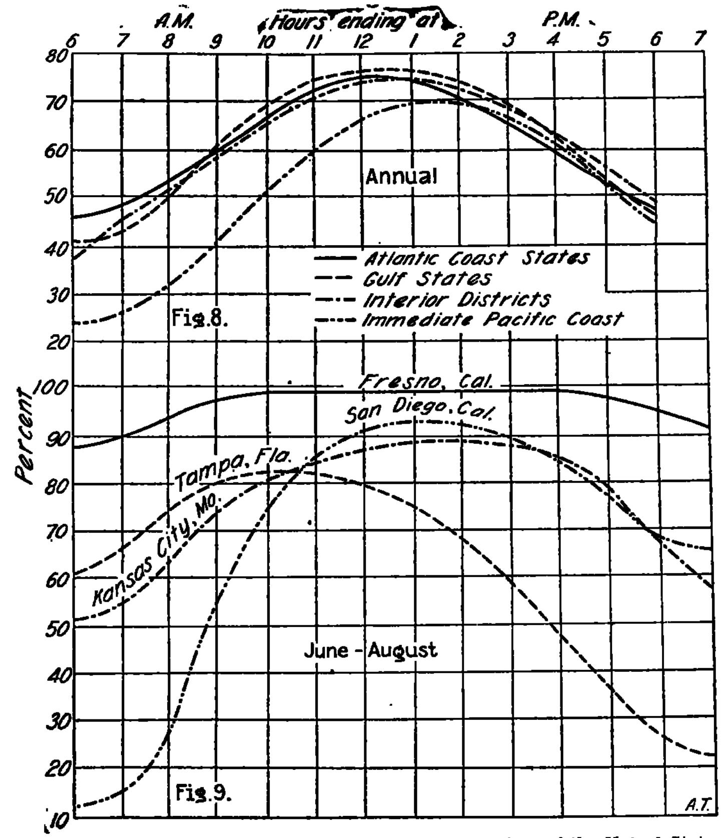


FIG. 8.—Diurnal distribution of sunshine in different sections of the United States, annual average. (Percentage of the possible amount.)

FIG. 9.—Diurnal distribution of sunshine, selected stations, for the summer season—June–August. (Percentage of the possible amount.)

The hour of maximum sunshine for the year, as a whole, varies for different sections of the country. In most localities the sunniest hour is from 12 to 1, although in some areas, including part of the upper Ohio Valley, Tennessee, and the east Gulf States, and the central Rocky Mountain and Plateau region, the maximum occurs from 11 to 12, while in much of the southern plains the sunniest hour is between 1 and 2. The earliest hour of maximum sunshine for the day, 10 to 11, is found in the Florida Peninsula and the southern Rocky Mountain districts. In the Gulf region the time of occurrence becomes progressively later from east to west. In the Florida Peninsula it is from 10 to 11; in the southern half of Georgia and of Alabama, 11 to 12; in the lower Mississippi Valley, 12 to 1; and in most of Texas, from 1 to 2. There is also a similar progression from the southern Rocky Mountains northward to the northern border districts.

TABLE 1.—*Percentage of possible amount of sunshine, monthly and annual (average for eight years, 1905–1912).*

Stations.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
ATLANTIC COAST.													
Eastport, Me	37	49	48	50	46	50	55	55	50	47	34	37	46
Portland, Me	55	64	64	60	57	64	67	64	59	61	49	54	60
Burlington, Vt	33	47	51	51	51	62	67	61	51	43	22	20	47
Northfield, Vt	38	53	58	54	50	60	67	62	54	48	31	33	51
Boston, Mass	44	57	60	62	61	69	72	67	58	60	48	46	59
Block Island, R. I	43	52	55	55	54	61	63	61	55	57	48	42	54
Providence, R. I	43	56	55	59	55	63	63	61	53	58	50	49	55
Hartford, Conn	44	56	55	56	52	57	59	52	47	51	38	42	51

TABLE 1.—*Percentage of possible amount of sunshine, monthly and annual (average for eight years, 1905–1912)*—Continued.

Stations.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
ATLANTIC COAST—contd.													
New Haven, Conn	47	59	59	59	57	64	66	61	57	62	53	52	58
Albany, N. Y	38	47	51	51	49	56	59	54	47	48	34	34	47
Binghamton, N. Y	29	39	44	44	46	53	53	47	43	40	23	22	40
New York, N. Y	50	62	62	64	62	66	72	62	63	63	59	52	62
Harrisburg, Pa	42	52	54	57	60	61	66	58	60	57	49	43	55
Philadelphia, Pa	45	57	54	57	56	56	64	54	56	58	53	48	55
Atlantic City, N. J	47	59	56	60	60	60	67	62	59	64	61	54	59
Baltimore, Md	46	61	59	63	65	63	70	63	64	64	57	48	60
Washington, D. C	39	54	52	56	62	56	62	52	53	61	55	48	54
Norfolk, Va	53	58	60	60	63	57	61	59	60	64	64	55	60
Richmond, Va	47	54	56	59	65	58	65	56	60	62	55	50	58
Lynchburg, Va	45	53	56	59	67	62	68	61	62	63	56	47	58
Wytheville, Va	43	49	51	55	62	59	59	55	60	58	56	40	54
Asheville, N. C	48	52	55	58	61	57	56	53	60	60	61	45	56
Raleigh, N. C	48	56	58	63	60	64	61	62	63	64	63	53	60
Wilmington, N. C	59	62	66	68	68	68	66	62	63	68	72	61	65
Charleston, S. C	61	62	69	70	69	69	63	67	68	68	70	56	66
Augusta, Ga	53	58	64	64	69	67	62	68	65	69	65	52	63
Atlanta, Ga	46	51	60	59	62	66	58	60	62	63	62	44	58
Macon, Ga	49	50	60	57	61	63	56	60	58	64	65	46	57
Savannah, Ga	56	58	67	65	66	67	58	62	57	62	67	52	61
GULF STATES.													
Jacksonville, Fla	56	58	69	68	69	68	64	63	61	60	59	53	62
Tampa, Fla	60	65	71	75	71	66	62	62	70	68	67	59	66
Mobile, Ala	54	60	63	67	75	70	59	62	63	70	69	48	63
Birmingham, Ala	46	51	56	56	53	63	57	61	64	64	64	42	56
Meridian, Miss	43	52	58	56	64	64	56	64	69	65	60	42	58
Vicksburg, Miss	49	53	61	61	70	71	62	69	74	70	62	45	62
New Orleans, La	52	51	60	56	62	63	54	58	53	61	56	42	56
Little Rock, Ark	48	55	57	57	64	69	68	70	74	71	61	49	62
Fort Smith, Ark	49	56	55	56	66	70	72	71	73	67	62	50	62
Bentonville, Ark	47	54	55	54	65	66	74	69	71	66	62	54	61
Oklahoma, Okla	51	59	56	59	65	72	73	78	76	68	66	60	65
Houston, Tex	61	57	57	54	70	73	66	74	72	68	61	42	63
Galveston, Tex	60	59	63	63	71	83	74	73	71	71	61	51	67
San Antonio, Tex	48	50	49	48	54	68	67	67	68	60	45	45	56
OHIO VALLEY AND TENNESSEE.													
Memphis, Tenn	46	55	58	60	65	70	70	72	74	71	64	44	62
Chattanooga, Tenn	37	45	50	52	61	60	56	59	60	65	56	39	53
Knoxville, Tenn	40	50	54	56	63	60	59	53	64	65	60	40	55
Lexington, Ky	30	42	46	56	64	62	61	63	61	58	46	31	52
Louisville, Ky	38	48	51	54	61	70	66	65	65	62	56	40	56
Evansville, Ind	54	50	56	60	82	78	81	77	79	67	52	51	66
Indianapolis, Ind	35	47	49	52	57	67	63	66	65	60	56	42	55
Cincinnati, Ohio	35	48	50	58	65	68	67	69	68	64	55	40	57
Columbus, Ohio	36	48	49	55	65	67	68	68	66	61	50	27	55
Parkersburg, W. Va	26	37	40	49	59	59	61	57	57	47	33	24	46
Elkins, W. Va	30	39	42	47	58	54	56	54	56	49	41	30	46
Pittsburgh, Pa	29	39	46	49	57	60	63	60	63	55	41	30	49
LAKE REGION.													
Canton, N. Y	35	48	52	50	54	63	65	62	55	46	28	28	48
Rochester, N. Y	29	40	48	53	59	66	73	68	63	55	31	25	51
Buffalo, N. Y	23	40	48	49	55	61	67	62	57	49	30	25	46
Erie, Pa	25	41	48	55	64	68	74	68	61	47	26	21	50
Cleveland, Ohio	26	37	47	52	62	66	68	66	63	51	34	25	50
Toledo, Ohio	32	41	49	51	62	65	69	68	63	54	40	31	52
Detroit, Mich	31	41	48	49	58	61	70	66	61	53	35	27	50
Port Huron, Mich	35	44	50	48	56	62	65	60	56	51	34	28	49
Grand Rapids, Mich	27	38	48	51	57	63	67	66	56	51	32	24	48
Grand Haven, Mich	24	34	52	54	59	68	71	68	60	52	33	24	50
Chicago, Ill	37	47	55	58	65	73	71	69	65	61	52	42	58
Lansing, Mich	45	52	64	66	72	76	76	68	59	55	31	32	58
Milwaukee, Wis	44	51	55	54	55	66	69	65	63	56	48	44	56
Green Bay, Wis	50	56	63	61	60	73	74	69	64	60	44	44	60
Escanaba, Wis	44	46	55	50	52	67	65	58	55	47	31	34	50
Sault Ste. Marie, Mich	28	42	51	49	50	63	62	53	47	36	17	19	43
Marquette, Mich	38	42	52	54	52	62	62	54	48	39	24	25	46
UPPER MISSISSIPPI VALLEY.													
St. Paul, Minn	50	62	62	63	59	66	75	70	62	58	48	44	60
La Crosse, Wis	45	59	56	57	58	68	71	63	60	56	42	41	56
Madison, Wis	43	51	52	51	54	65	65	62	59	52	42	40	53
Charles City, Iowa	52	58	55	62	67	64	79	72	67	66	54	57	63
Dubuque, Iowa	43	51	51	53	55	64	66	60	54	56	47	44	54
Des Moines, Iowa	46	47	59	58	60	65	70	70	60	62	54	52	59
Peoria, Ill	44	57	60	62	68	74	73	72	66	65	60	50	63
Springfield, Ill	45	55	56	57	67	70	71	74	67	66	62	52	62
St. Louis, Mo	42	51	56	57	67	64	66	66	64	60	58	44	58
MISSOURI VALLEY.													
Columbia, Mo	48	57	58	57	67	66	69	72	61	64	58	55	61
Kansas City, Mo	48	57	62	61	68	74	76	75	59	59	53	49	62
Topeka, Kans	53	60	64	63	66	68	74	75	66	65	66	59	65
Dodge City, Kans	58	64	62	70	70	75	77	75	77	73	71	70	70
Concordia, Kans	60	64	76	73	70	77	81	80	72	72	75	63	72
North Platte, Nebr	62	67	69	64	62	70	76	72	67	69	64	60	67
Omaha, Nebra	47	57	54	58	59	64	68	67	59	61	51	51	58
Sioux City, Iowa	44	56	59	55	57	63	69	72	64	64	59	48	59
Yankton, S. Dak	48	62	60	57	60	66	71	67	62	65	58	50	60
Rapid City, S. Dak	55	60	67	63	59	65	71	70	65	65	57	51	62
Huron, S. Dak	53	66	60	64	64	68	74	74	65	62	54	50	63
Devils Lake, N. Dak	55	59	59	62	52	58	68	62	60	54	48	45	57
Bismarck, N. Dak	56	62	56	64	56	60	71	66	59	59	50	49	59
Williston, N. Dak	45	60	55	58	54	61	69	65	59	51	43	40	55

TABLE 1.—*Percentage of possible amount of sunshine, monthly and annual (average for eight years, 1905–1912)*—Continued.

Stations.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
MOUNTAIN REGION.													
Havre, Mont	51	58	66	66	60	70	76	71	62	58	43	42	60
Kalispell, Mont	27	37	53	55	48	54	70	63	54	52	27	18	46
Helena, Mont	50	61	70	66	57	62	77	70	60	61	48	48	61
Yellowstone Park, Wyo	38	52	62	66	51	63	75	73	63	62	52	49	59
Sheridan, Wyo	57	64	63	60	61	70	72	63	55	55	47	54	60
Lander, Wyo	66	74	76	73	68	73	76	78	70	68	55	62	70
Cheyenne, Wyo	62	67	64	64	57	68	66	69	63	65	61	64	64
Grand Junction, Colo	49	62	61	67	67	78	73	71	72	72	64	56	66
Durango, Colo	68	72	70	72	78	85	77	78	83	81	77	71	76
Denver, Colo	63	68	66	66	59	69	68	65	66	70	62	65	66
Pueblo, Colo	78	79	76	73	74	78	72	73	78	78	75	81	76
Amarillo, Tex	73	73	78	79	80	84	77	80	80	74	73	75	77
El Paso, Tex	74	79	80	86	91	89	74	75	84	85	76	72	80
Roswell, N. Mex	66	63	67	69	75	75	67	69	76	74	67	62	69
Santa Fe, N. Mex	71	69	69	73	78	82	65	68	80	80	72	74	73
Phoenix, Ariz	76	78	77	88	91	94	88	82	88	92	83	76	84
Yuma, Ariz	77	83	84	94	95	97	89	92	93	90	88	79	88
Tonopah, Nev	60	65	64	76	74	82	80	88	81	72	73	63	73
Modena, Utah	55	60	60	66	76	84	71	75	75	74	69	59	69
Salt Lake City, Utah	42	45	55	64	63	71	74	72	70	68	56	39	60
Winnemucca, Nev	49	58	67	75	76	83	90	92	84	77	64	50	72
Pocatello, Idaho	44	57	59	68	64	63	82	81	77	64	57	44	63
Boise, Idaho	36	49	60	71	70	76	88	88	77	70	50	36	64
Baker, Oreg	38	48	58	64	65	64	78	86	77	70	53	40	62
Walla Walla, Wash	26	38	62	70	69	75	87	81	69	62	37	22	58
Spokane, Wash	23	38	56	65	62	68	81	76	67	53	24	19	53
PACIFIC COAST.													
Seattle, Wash	33	35	48	52	50	52	64	57	48	37	25	22	44
Tacoma, Wash	21	29	46	55	50	53	65	61	47	30	17	14	41
North Head, Wash	28	42	49	52	48	46	49	50	50	45	30	30	43
Portland, Oreg	23	35	45	53	50	56	72	63	50	39	26	20	44
Eureka, Calif	28	34	43	51	48	45	37	37	40	42	33	34	39
Sacramento, Calif	39	58	61	78	79	86	96	96	89	81	63	45	73
San Francisco, Cal	40	50	54	68	69	68	61	59	64	71	56	54	60
Fresno, Calif	41	58	60	81	87	94	96	97	90	86	76	43	76
San Luis Obispo, Calif	46	58	54	66	66	70	74	76	74	74	67	62	66
Los Angeles, Calif	64	64	58	64	67	71	76	79	78	78	73	73	70
San Diego, Calif	63	62	58	65	60	61	65	72	75	75	73	73	67

THE SUN AS A SOURCE OF POWER.

The problem of harnessing the radiation of the sun, and converting it into power in such a manner as to render the results of commercial value, is not a new one. The attempt to use reflecting devices may be said to date from De Caux in 1615 and Buffon in 1747. But, aside from the mere general interest in the problem, its significance and importance are accentuated by the realization that the coal supply of the world is steadily being depleted. In addition, in tropical regions, where solar engines would give the greatest promise, coal is scarce, and a satisfactory device for obtaining power from radiation which would otherwise be used only in heating the earth's surface would be most welcome.

While it is interesting, it is not necessary, in this connection, to consider the opinions which have been advanced as to the reason for the maintenance of the sun's heat, but it is valuable to know the tremendous amount of energy which reaches the earth's surface daily. The *Scientific American* of October 7, 1916, says:

> The great glowing surface which the sun presents to us, even considered as a flat disk, has the enormous area of 585,750,000,000 square miles, each square foot of which emits the tremendous amount of about 12,500 horsepower. The average radiant energy received on the surface of the earth [in middle latitudes] at noon on a clear day is about 5,000 horsepower per acre.

Sir Oliver Lodge, who discussed this question before the Royal Society of Arts on December 10, 1919, expressed the opinion that the greatest good will be derived from the sun through the promotion of agriculture, inasmuch as the leaves of plants, unhampered by any efficiency limit imposed by the laws of thermodynamics, will use most efficiently the incident radiation. Dr. Horace Brown has shown, however, that vegetation is not the most efficient user of solar heat, for the amount of solar energy stored is less than 2 per cent of that which reaches the leaves. There appears to be a difference of opinion, also, in regard to the maximum possible thermal efficiency obtainable from such devices as have been suggested. These figures vary from 2 to more than 40 per cent, although they are based on many principles, theoretical and practical, and may not be of equal value. It can not be denied that the idea of a factory deriving its power from the solar radiation incident upon its roof is an attractive one, in spite of the general opinion of its impracticability.

Solar engines have been constructed which have given promise of considerable practical importance. Perhaps the most important of these is the one at Meadi, near Cairo, Egypt. This consists of five 205-foot boilers placed on edge and in the focus of five channel-shaped mirrors of parabolic cross section, giving a total area of 13,269 square feet. This plant gave as its best run for an hour 1,442 pounds of steam at a pressure of 15.8 pounds per square inch, which is equivalent to 63 horsepower per acre of land occupied by the plant. Tests have been made upon other engines of similar design but of different size. For example, it was found that the boilers were more productive when covered with glass. Meterological conditions also affect the steam production. Humidity, it was found, exerted so much influence that a decrease of 20 per cent gave an increased steam production of 30 per cent.[1]

Not all the theories for the utilization of the sun's energy are built around the idea of concentration of the sun's rays upon boilers, but others have been advanced in the more speculative field of electromagnetism. It is argued by Mr. A. A. Campbell Swinton, in a letter to *Nature*,[2] that by methods analogous to those which have produced such fruitful results in wireless communication, it may be possible to convert incident energy directly into usable electrical energy. The basis for his argument is that since the difference between the electromagnetic waves which reach us from the sun, and those emited from a wireless station, lies only in the wave length, it is possible to use the analogy of wireless development in predicting what may come from this line of experimentation. He predicts that the efficiency of this method, if it were devised, would be quite high, perhaps not less than 50 per cent. This idea seems quite attractive and perhaps more promising than the older idea of the heat engine.

Other interesting devices have been made of lesser practical importance. It is said[3] that in subtropical regions, where coal is scarce, such as Egypt, the Punjab, and the Karoo of South Africa, teakwood boxes, blackened within, fitted with glass tops, and properly insulated, have been found to register from 240° to 275° F. in the middle of the day, and, with the addition of an auxiliary mirror, to reach even 290°. The applications of such ovens are many, and there is no other expense than the initial construction. This is employed in those regions for cooking and baking as well as many other purposes.

In view of the declining natural resources of the world, the increasing studies in solar activity, and the application of electrical methods and devices, it is not idle to hope for an efficient and practical method of converting the sun's heat into usable commercial power.—*C. Le Roy Meisinger.*

[1] Swinton, A. A. Campbell: Power from the sun, *Nature*, Dec. 18, 1919, p. 392.
[2] *Scientific American Supplement*, Sept. 15, 1917, p. 176.
[3] Ackermann, A. S. E.: The utilization of solar energy, abstract in *Nature* (London), May 27, 1915, pp. 358–360, 3 figs.